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Direct Time-of-Flight Ranging with the SiPM based Gen1 LiDAR Demonstrator

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APPLICATION NOTE

The Silicon Photomultiplier (SiPM) is a single-photon sensitive, high performance, solid-state sensor. It is formed of a summed array of closely-packed Single Photon Avalanche Photodiode (SPAD) sensors with integrated quench resistors, resulting in a compact sensor that has high gain (~$1x10^6$), high detection efficiency (> 50%) and fast timing (sub-ns rise times), all achieved at a bias voltage of ~30 V.

There are an increasing number of ranging and sensing applications looking to benefit from low-power, highperformance SiPM technology. In particular, LiDAR (light detection and ranging) applications that use eye-safe near infrared (NIR) wavelengths such as Automotive ADAS (Advanced Driver Assistance Systems), 3D depth maps, mobile, consumer and industrial ranging.

In order to take advantage of the SiPM sensor's high gain and high bandwidth, the use of direct time-of-flight (ToF) can be used to provide accurate ranging with the lowest power budget. The high sensitivity of ON Semiconductor's SiPM allows the use of low power lasers for increased eye-safety.

ON Semiconductor have created a software model that allows for accurate determination of system performance for a wide range of input conditions, as well as a hardware ranging demonstrator incorporating a SiPM sensor. The demonstrator has been used to establish a realistic ranging test bench in the laboratory and to validate results from the model.

This document gives an overview of the model and Gen1 demonstrator from ON Semiconductor and presents results of short-range (up to 5 m) testing and simulation. The results from the Gen1 demonstrator are shown to validate the model. The model has also been optimized for ranging with the SiPM to 100 m, and shown to give < 10 cm resolution at this distance. The laboratory measurements and model demonstrate that by limiting the field of view onto the SiPM sensor it is possible to range in 100 klux solar conditions which are a requirement for automotive ranging systems.

KEY ADVANTAGES OF ON SEMICONDUCTOR SiPM FOR RANGING APPLICATIONS

Previously, sensors available for direct ToF ranging suffered serious short-comings. In particular, APDs suffer from a lack of uniformity and a high temperature coefficient that both contribute to poor range accuracy. SiPM sensors from ON Semiconductor overcome these problems, and have additional benefits:

- Single Photon Detection at 905 nm
- Responsivity of 530 kA/W at 905 nm
- Low Power – Lower Operating Voltages and Simple Readout Electronics Allow a Low Power Design
- High Bandwidth and Fast Response Time – Minimize Range Measurement Time
- Ability to Take Advantage of Low Laser Power Direct ToF Ranging Techniques
- Low Noise and High Gain – Good Signal to Noise Ratio (SNR) is Achievable
- Standard CMOS Fabrication Process − Low Cost, Highly Uniform and Scalable Production
- Compact MLP Package − Reflow Solder Compatible (Tape & Reel Delivery)

AMBIENT LIGHT REJECTION WITH SiPM

- **Aperture Limit** – minimize sensor field of view to overlap with pulsed source. Highest resolution and signal to noise is achieved by making laser spot coincident with sensor spot.
- **Bandpass Optical Filter** – ±25 nm bandpass will reduce ambient light from 1000 W/m^2 to 38 W/m^2.
- **Shorten Laser Pulse** – provides a higher optical peak power.

RANGING MODEL

ON Semiconductor has created a model using MATLAB to simulate a SiPM based ranging systems with variety of conditions. The results from the model can then be verified with the Gen1 ranging demonstrator hardware, described below. The ranging model consists of two main parts:

Analytic: This calculates the photon flux incident on each SiPM cell due to noise (ambient light) and signal (laser light) from a reflecting target in the Field of View (FoV) of the cell itself. The diagram on the right shows the input parameters (red, blue and purple boxes).

Monte Carlo: (orange box) sensor output waveforms can be simulated and directly compared to experimental waveforms from the ranging demonstrator hardware. Readout techniques are implemented for full system-level simulation allowing the estimation of performance benchmarks i.e. ranging accuracy. The SiPM sensor parameters (e.g. PDE, recovery time, shown in the green box) and information on the readout circuitry (e.g. amplifier gain, TDC resolution) are included.

In addition, the model allows the user to select either an APD or PIN photodiode model (for comparison with the SiPM) and also the readout mode, e.g. Leading Edge Discrimination (LED) or Time Correlated Single Photon Counting (TCSPC).

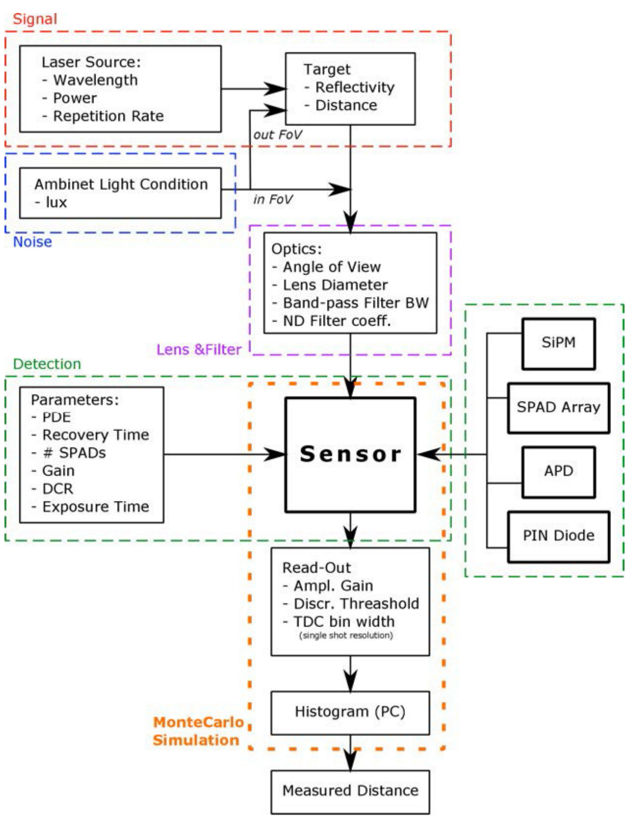

Figure 1. Block Diagram of the ON Semiconductor Ranging Model

RANGING DEMOSTRATOR

ON Semiconductor's direct ToF Gen1 ranging demonstrator is an engineering prototype used to demonstrate SiPM technology in ranging applications and to corroborate the results obtained from the ranging model. A block diagram of the demonstrator is shown in Figure 2, and a photo in Figure 3.

The Gen1 demonstrator consists of:

- Pulsed laser with collimation optics
- Sensor with detection optics
- Timing and data processing electronics
- Software that creates histograms from the data and allows system configuration.

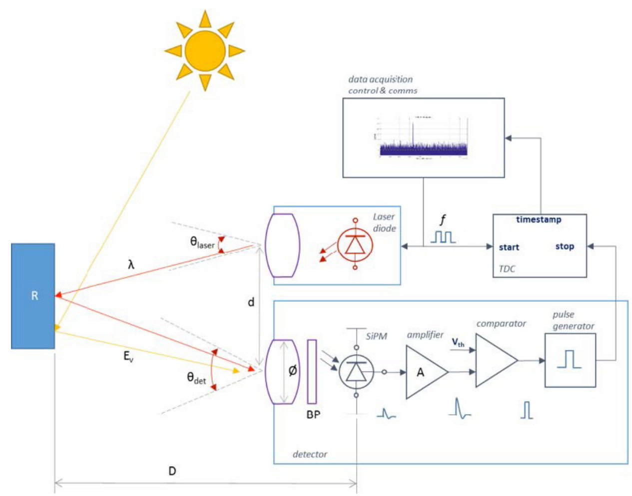

Figure 2. The ON Semiconductor Gen1 Ranging Demonstrator Concept

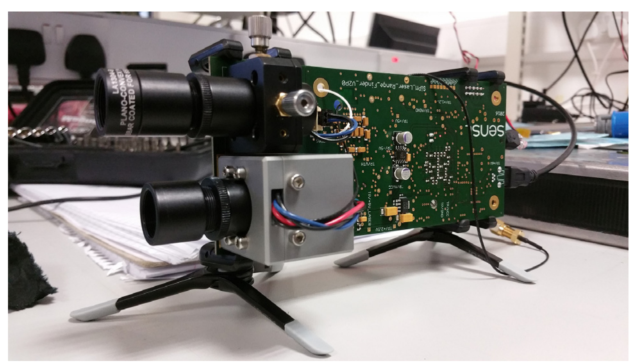

Figure 3. Photo of the Gen1 Ranging Demonstrator

The specifications of the Gen1 demonstrator are listed in Table 1. In this configuration, imaging up to 5 m with 1 mm accuracy is possible.

Table 1. DEMOSTRATOR SPECIFICATIONS FOR ToF RANGING UP TO 5 m

Parameter	Specification
Sensor	MicroFC−10020−SMT
Laser Wavelength	905 nm
Laser Pulse Width	150 ps
Laser Frequency	150 kHz
Ambient Illuminance	250 lux
Acquisition Time	400 ms
Acquisition Method	LED
Laser Peak Power	1.39W (Class 1)
Laser Beam Divergence	0.0573° (1 mrad)
Detector Lens Aperture	11.4 mm
Optical Filter FWHM	10 nm
Detector Angle of View	1.4°
TDC Resolution	93.75 ps
Target Reflectivity	90% (White Paper)

VALIDATION OF THE RANGING MODEL USING THE GEN1 RANGING DEMOSTRATOR

The model was configured with the system parameters of the demonstrator and simulated with the same distance to target and ambient light conditions (as in Table 1). The simulated results were then compared to the measured results from the Gen1 Ranging Demonstrator with good correlation as shown in Figure 4 and Figure 5. This validates the model and provides a means to design a system for different use cases.

RANGING MODEL RESULTS UP TO 100 M

Having been validated by data from the demonstrator, the ranging model was then used to simulate ranging up to 100 m. Table 2 lists the specifications used in the model. The parameters that have changed from Table 1 (ranging up to 5 m) are shown in bold. Figure 6 shows the simulated histogram, Figure 7 the ranging over the full 10 m−100 m range showing good linearity, and Figure 8 shows the simulated range resolution, that demonstrates that sub-10cm resolution can be obtained at 100 m under 100 klux solar ambient conditions.

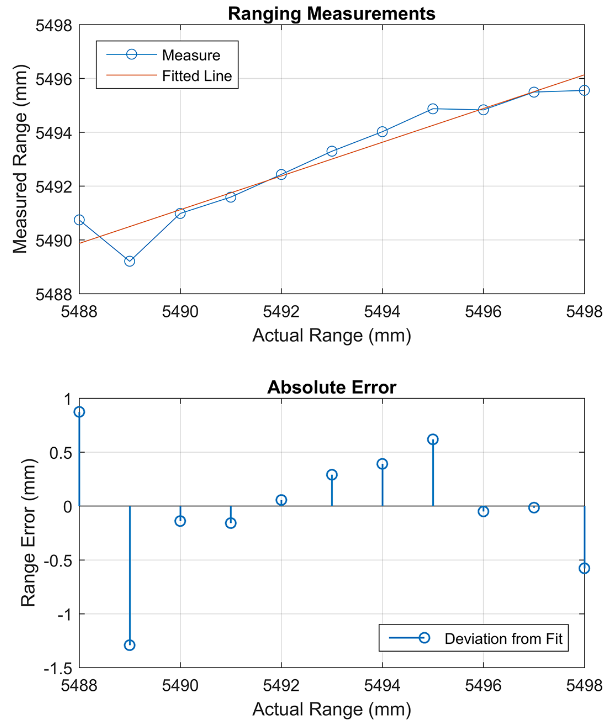

Figure 4. Gen1 Ranging Demonstrator Measured Data at 5 m

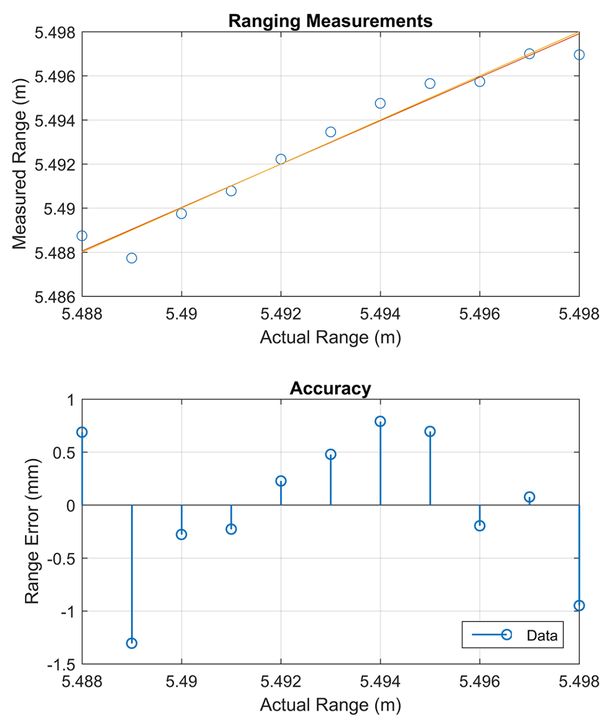

Figure 5. MATLAB Model Simulated Data at 5 m

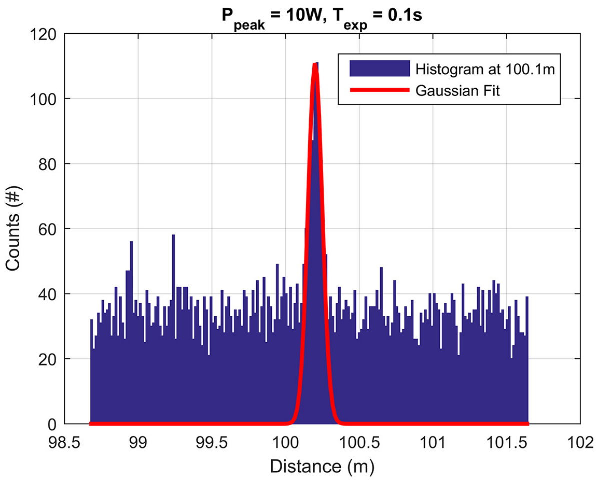

Figure 6. Simulated Histogram for 100 m Distant Target

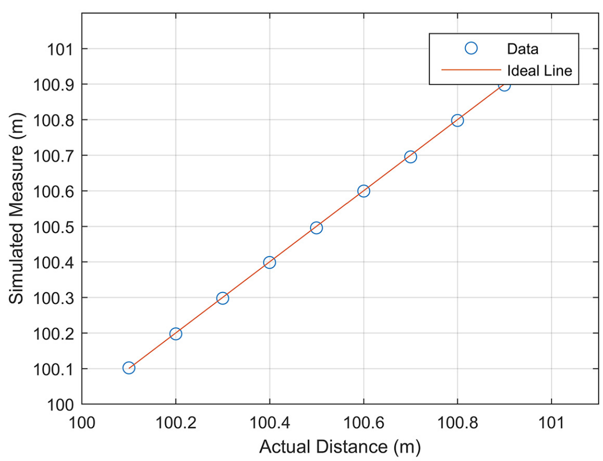

Figure 7. Ranging at 100 m, Using the Parameters in Table 2 and Giving < 10 cm Resolution

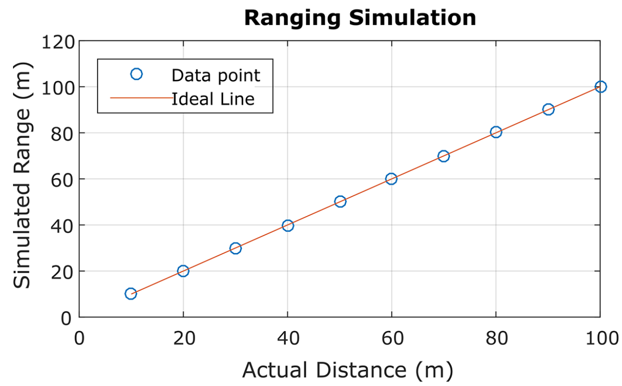

Figure 8. Ranging Data for 10 m Up to 100 m, Showing Good Linearity

Table 2. MODEL SPECIFICATIONS FOR DIRECT ToF RANGING AT 100 m

Parameter	Specification
Sensor	MicroFC−10020−SMT
Laser Wavelength	905 nm
Laser Pulse Width	667 ps
Laser Frequency	150 kHz
Ambient Illuminance	100 klux
Acquisition Time	100 ms
Acquisition Method	LED
Laser Peak Power	10 W
Laser Beam Divergence	0.0573° (1 mrad)
Detector Lens Aperture	11.4 mm
Optical Filter FWHM	50 nm
Detector Angle of View	0.2°
TDC Resolution	100 ps
Target Reflectivity	92%

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